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REPORT NO.
TDR-169(3250-45)TR-1

Electronics Research Program

Investigation of Millimeter-Wave Modulation and Signal Processing Techniques

SEMIANNUAL TECHNICAL REPORT

(1 January – 30 June 1963)

31 OCTOBER 1963

Prepared by L. A. HOFFMAN, H. J. WINTROUB, and C. J. CARTER
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Prepared for COMMANDER SPACE SYSTEMS DIVISION
UNITED STATES AIR FORCE
Inglewood, California

LABORATORIES DIVISION • AEROSPACE CORPORATION

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AEROSPACE CORPORATION
El Segundo, California

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ABSTRACT

Research concerning

An investigation of millimeter-wave modulation and signal processing techniques, ~~was undertaken in April 1963~~. The purpose of this investigation is to advance the technology and determine the feasibility of millimeter-wave communication systems in the region between 10 mm (30 Gc) and 1 mm (300 Gc). Initial effort centers on two problem areas: low-noise receiver front-ends and stable millimeter-wavelength reference sources. A parametric amplifier approach to low-noise receiver design is being studied, as is the use of a phase-locked klystron system as a possible stable reference source. Fabrication and design status of the klystron system is presented. The space radio facility boresight range between Aerospace, El Segundo and San Pedro Peak, Palos Verdes has been selected for various demonstrations of the program and arrangements are being made to establish a communication link between these two points.

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I. INTRODUCTION

A. PURPOSE AND SCOPE

In April 1963, Aerospace began a program to investigate millimeter-wave modulation and signal processing techniques. The objective of this program is to explore the technological problems of those techniques as applied to communication systems in the millimeter wavelength region, i.e., 1 mm (300 Gc) to 10 mm (30 Gc). The program as begun follows the Program Plan essentially as submitted and will consist largely of experimental work intended to advance the technology and to demonstrate the feasibility of such systems.

B. TECHNOLOGICAL SIGNIFICANCE

The significance of attaining a capability in millimeter-wave communication techniques is evident upon consideration of the following possible applications of those techniques:

Space to Ground or Ground to Space. Security of communications is possible because of the narrow beamwidth and good sidelobe control possible with millimeter-wave techniques along with the rapid absorption that off-beam energy experiences in traversing the atmosphere.

High Altitude. At high altitude the attenuation is low except exactly at the frequency of the narrow absorption lines. Thus, most frequencies are usable given sufficient power and narrow beamwidths. In addition, security from detection at ground level can be obtained if the frequency is within one of the atmospheric-pressure absorption bands.

Ground to Re-entering Space Vehicle. Certain millimeter wavelengths will be useful for re-entry communications because of their ability to penetrate the plasma sheath which surrounds a body re-entering the earth's atmosphere.

2) spacecraft rendezvous ranging systems which require high measurement precision;

3) extremely high data-rate communication systems made possible by relatively unlimited available bandwidth;

4) a ground-synchronizing channel in a precision radio guidance system of the interferometer type in which the errors, due to the adverse effects of multi-path reception, are eliminated by means of narrow beamwidths and small antennas.

II. TECHNICAL DISCUSSION

A. INTRODUCTION

Since this report period covers only the early stages of the program, relevant material is limited. Initial effort has been directed into two main channels: analysis on a 94 Gc parametric amplifier and analysis and experimental work on a stable 94 Gc reference source.

Work was begun at 94 Gc for two principal reasons: a "window" or low atmospheric-attenuation region exists in the vicinity of 94 Gc, (Ref. 1); related work is being done at Aerospace at this frequency which, as was anticipated, has been of invaluable aid in getting this program started.

B. PARAMETRIC AMPLIFIER

1. General

Millimeter-wave communication systems can be fully utilized only after the development of greatly improved components. One very important part of any transmission link is the front-end of the receiver. The state of the art at 94 Gc in low noise receivers needs considerable improvement; for example, some of the best mixers have a noise figure of 20 db, and 25 or 30 db is not uncommon.

The parametric amplifier is one approach to low-noise receiver design which holds good promise of success at 94 Gc. A varactor with a cutoff frequency of about 500 Gc would make possible a parametric amplifier at 94 Gc with a noise figure well under 10 db. Semiconductor materials are available which have a theoretical capability of operation at this frequency. For example, gallium arsenide has a theoretical upper limit cut-off frequency of approximately 1000 Gc, and indium antimonide has an estimated limit of about 2000 Gc (Ref. 2).

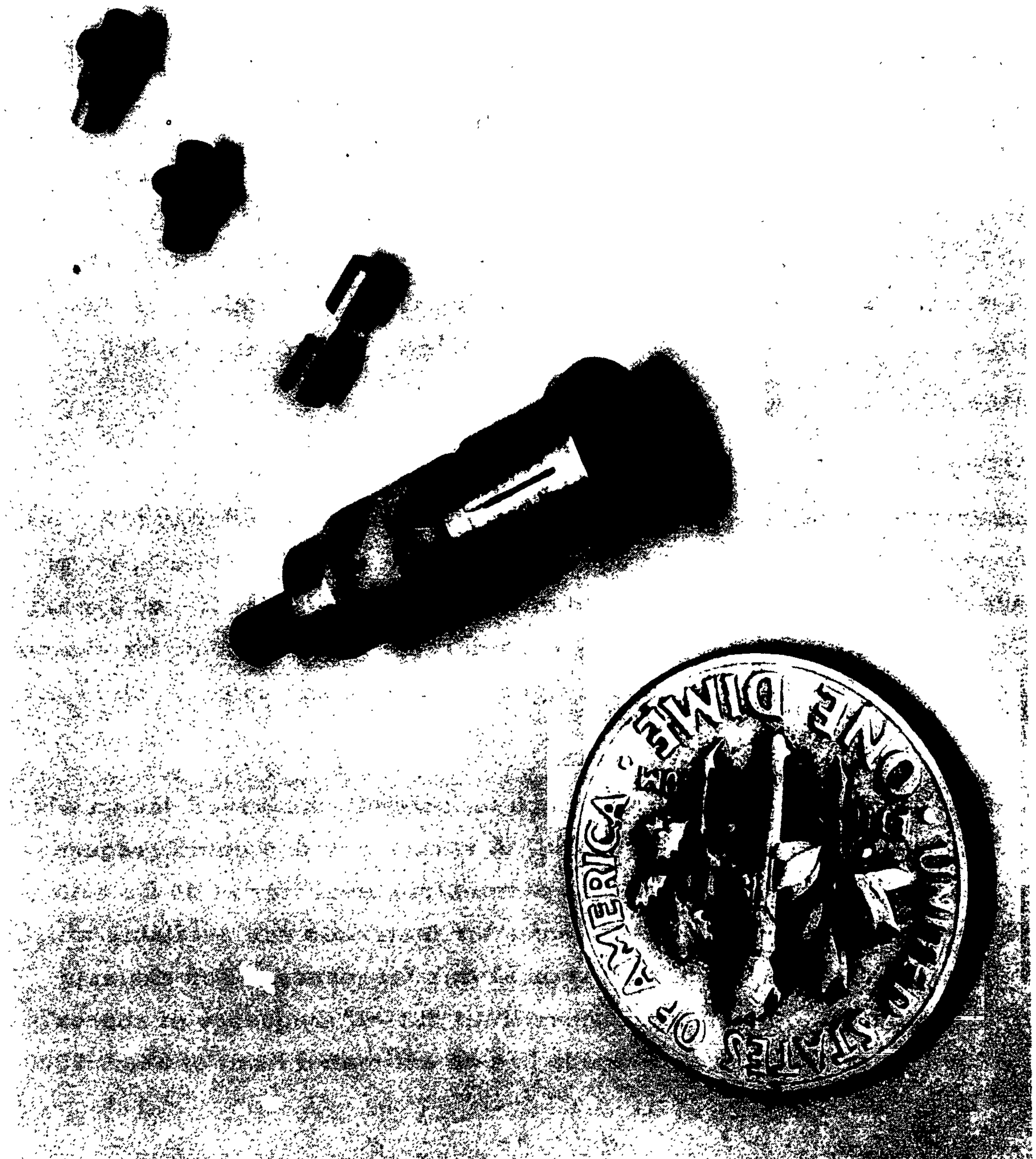

Fig. 1. Typical Varactors

2. Present Status

The program to develop a 94 Gc parametric amplifier is in the beginning stages. Enough theoretical exploratory work has been done to indicate a reasonable probability of success. However, there has been no experimental work as yet.

Typical varactors used at lower frequencies are shown in Fig. 1. The smallest of these varactors is larger than the opening in the waveguide which is required at 94 Gc. A new varactor package designed for this frequency is shown in Fig. 2. (One varactor manufacturer, VARAD, has expressed an interest in producing this item and has done some preliminary work.) In this design the varactor is built within a short section of the waveguide; consequently, it will be necessary to make all quality measurements at or near the final operating frequency. A survey of varactor test procedures has shown that it is standard procedure in the industry to test varactors at X-band; however, this method is not satisfactory for this program. No varactors will be accepted for purchase until they have passed a test at Aerospace at 94 Gc.

3. Future Plans

An attempt will be made to develop a four-frequency parametric amplifier in which the pump frequency is near or just below the signal frequency. This technique has been demonstrated successfully at lower frequencies; however, it is not normally used for any signal frequency up to about K-band, because better noise performance can be obtained by using a pump frequency several times the signal frequency. However, for a 94 Gc signal frequency it is an attractive configuration, because there are very few signal sources available to provide pump power at a higher frequency.

In the proposed parametric amplifier, the four frequencies of interest are the signal, the pump, the second harmonic of the pump, and the idler. The second harmonic of the pump frequency is the true source of power which produces gain at the signal frequency.

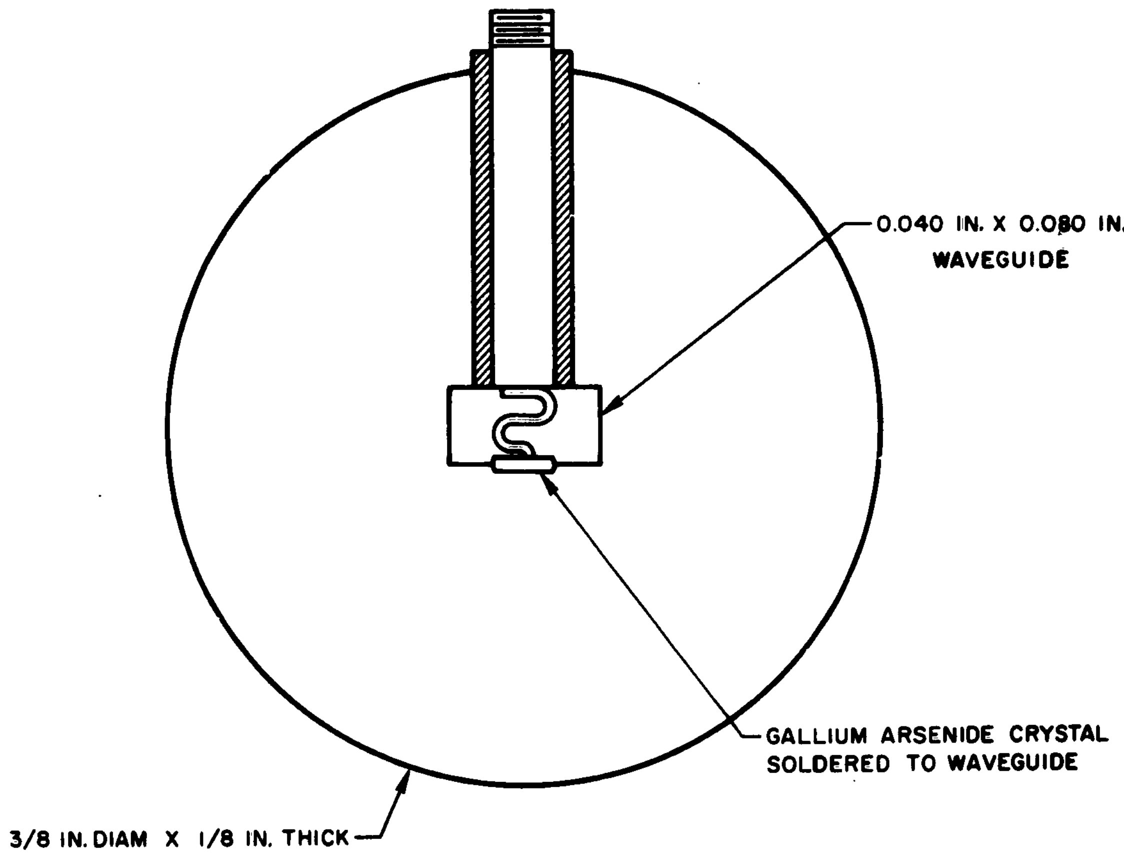

Fig. 2. Millimeter-Wave Varactor

A second configuration which will be studied is the five-frequency parametric amplifier. It is the same as the four-frequency configuration except that a signal is extracted which is the difference between the pump frequency and the signal frequency. This configuration, if successful, would eliminate the need for a mixer following the parametric amplifier, since the output would be at the IF frequency.

C. STABLE 94 Gc REFERENCE SOURCE

1. General

Of major importance to the experimental effort of this program are reference sources of known and stable frequency. Undesirable phase noise and/or frequency drift and bias are detrimental to system performance. Excessive long-term drift may eventually translate signals out of their passbands or cause distortion effects because of unsymmetrical sideband amplification; whereas, excessive short-term jitter contributes to a reduced threshold and poor sensitivity.

In obtaining these references, a first step is to determine the frequency and phase stability, control characteristics, and temperature and supply-voltage dependence of available millimeter-wave sources. To aid this determination, elements not readily available, such as wide-band phase detectors and FM discriminators, will be fabricated and integrated with general-purpose test equipment to perform appropriate laboratory measurements.

2. Present Status

Early in the program, it became apparent that a stable millimeter-wave source would require stringent parameter and environment control. For this reason, a klystron filament supply was designed and fabricated in the laboratory (Fig. 3). This is a highly regulated, constant current dc supply and is necessary because of the output frequency sensitivity vs filament-supply current, i.e., 2 Mc per ma in a total of 1800 ma for an Amperex unit.

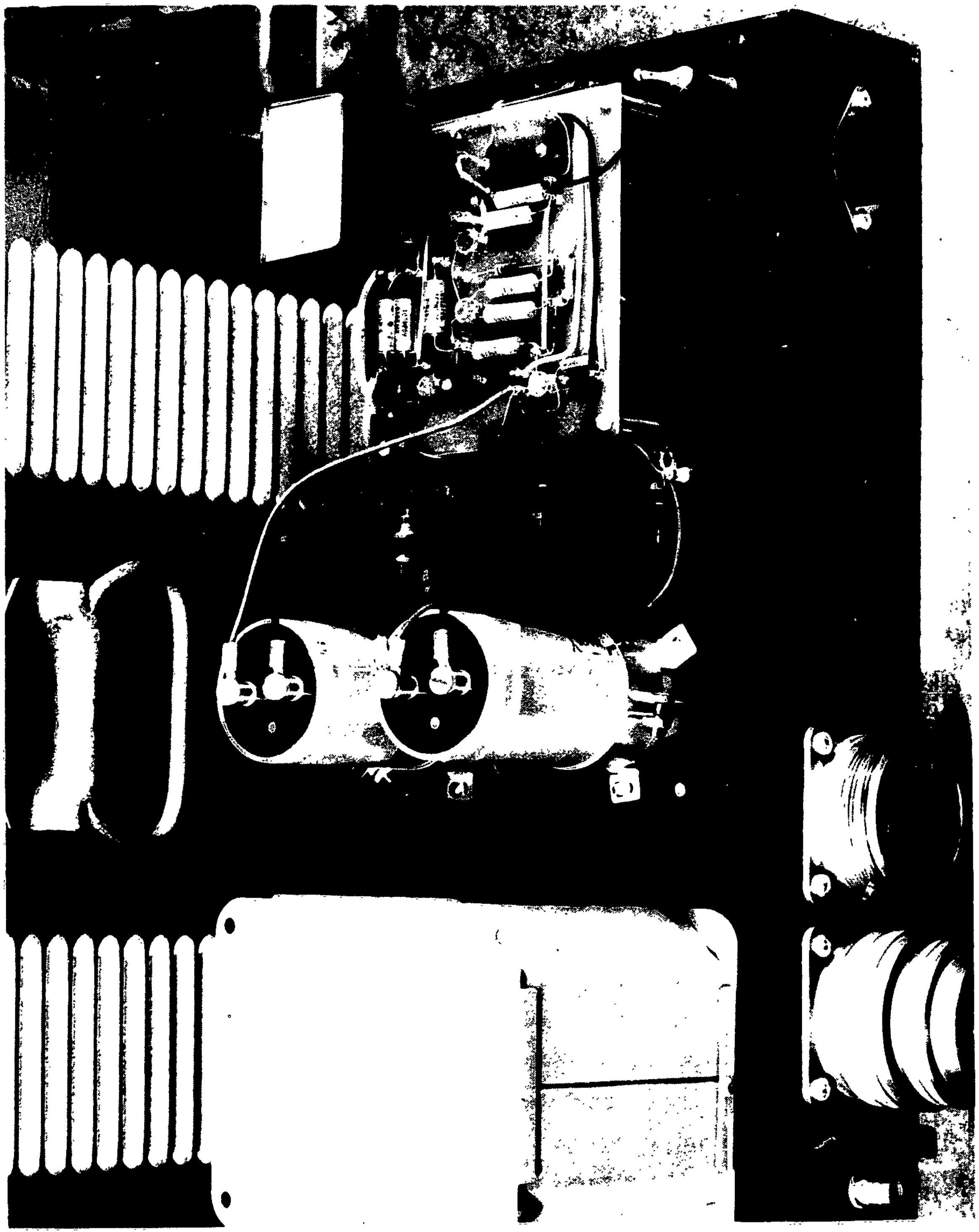

Fig. 3. Cover-off View of Amperex Klystron Regulated Filament Supply

Before parameter frequency dependence measurements could be made, it was necessary to eliminate the large temperature-sensitivity of the klystron output frequency. To accomplish this, a klystron oil bath was designed and constructed in the laboratory (Fig. 4).

Fig. 4. 94 Gc Klystron Oil Bath, Close-up

At inception of the program, a study was made on phase-locking of klystrons to the multiplied output of stable quartz crystal oscillators. This, theoretically, would yield a relatively high-powered millimeter-wave source with the stability of the low-frequency crystal oscillator. The simplified block diagram of such a system is shown in Fig. 5.

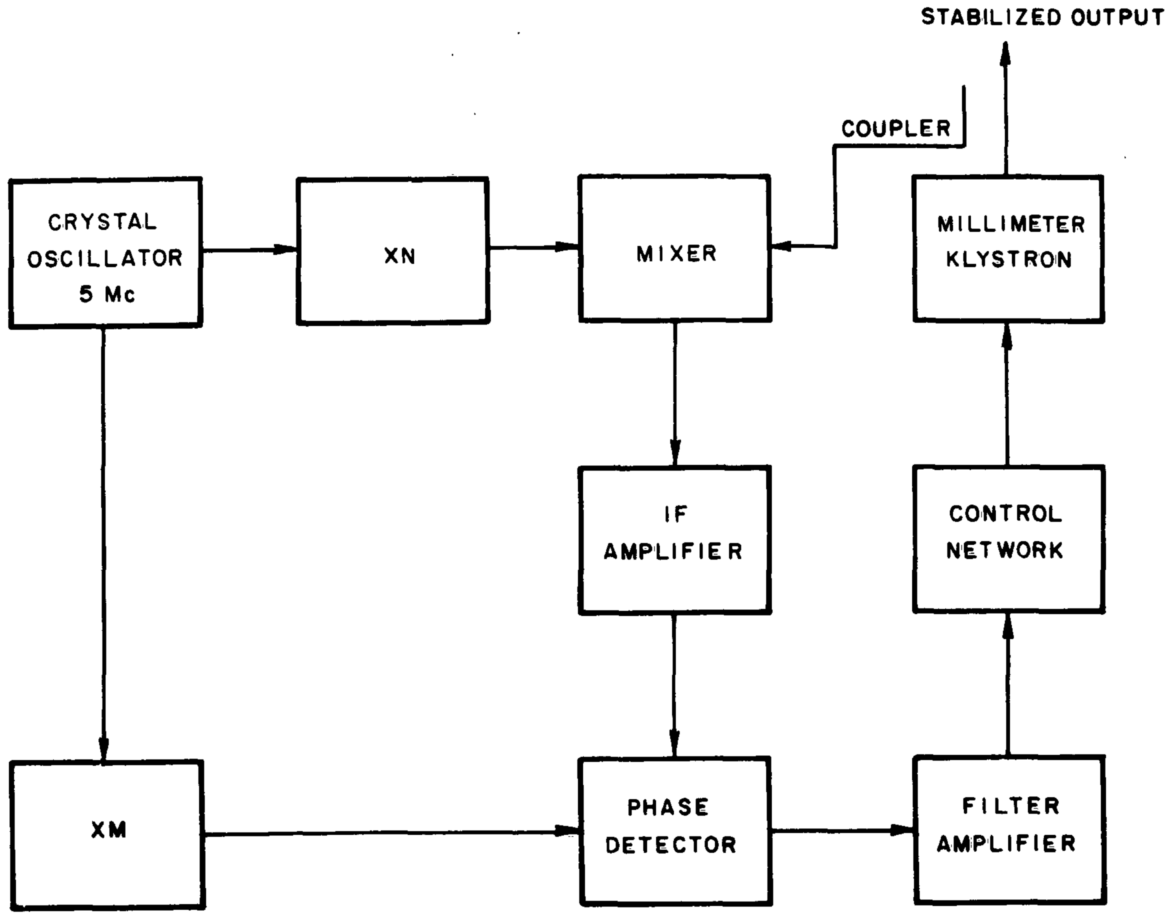

Fig. 5. Proposed Phase-Lock Stabilized Millimeter-Wave Klystron, Simplified Block Diagram

The first configuration of the phase-locking experiment will not be fabricated as shown in Fig. 5 but as shown in Fig. 6. The configuration shown in Fig. 6 will be implemented first because of the problems involved with the large multiplication factor (approximately 19, 000) in achieving sufficient power output and harmonic suppression at the end of the multiplication chain. However, effort on the Fig. 5 configuration will continue in parallel.

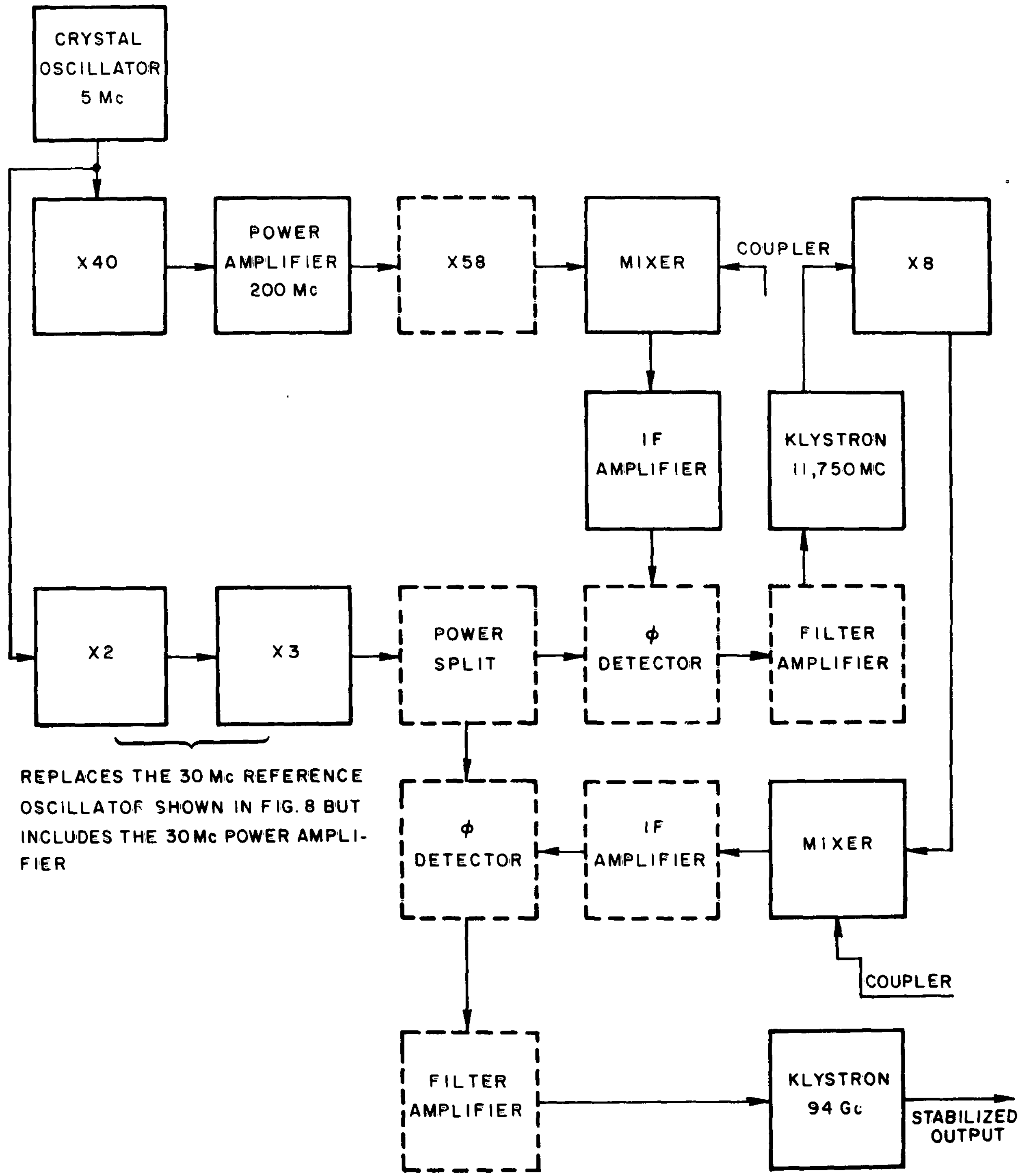

Fig. 6. Alternative Phase-Lock Millimeter-Wave Klystron, Block Diagram

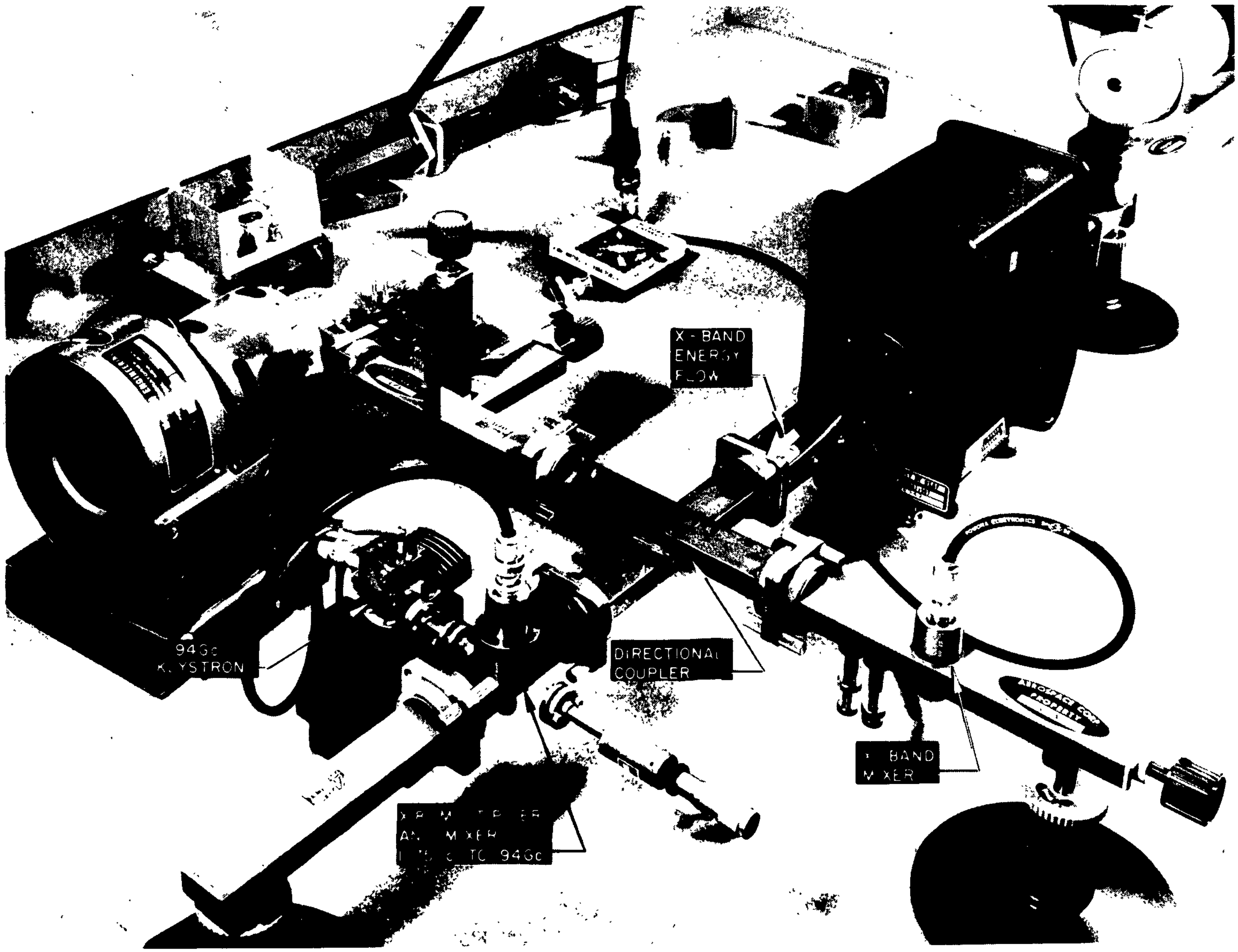

Fig. 7. Millimeter-Wave Klystron Phase-Lock Test Set-Up

As shown in Fig. 6, phase-lock is first accomplished at X-band. Then this relatively high-power, harmonic-free output is multiplied further to 94 Gc. The millimeter-wave klystron is then phase-locked to the output. All of the blocks, except those shown by dotted lines, have been either obtained or fabricated and tested. Some of the system blocks in a test set-up, including a directional coupler which was designed and fabricated at Aerospace, are shown in Fig. 7. The X58 block will be implemented by means of a step-recovery diode harmonic-generator. Shown in Fig. 8 are several of the elements of the block diagram of Fig. 6 which also have been designed and fabricated at Aerospace specifically for this program.

3. <u>Future Plans</u>

Upon successful completion of the first phase-lock system, effort will be intensified on the simpler version. Both systems will be required for testing and verification of performance, and they will be invaluable in future millimeter-wave experiments.

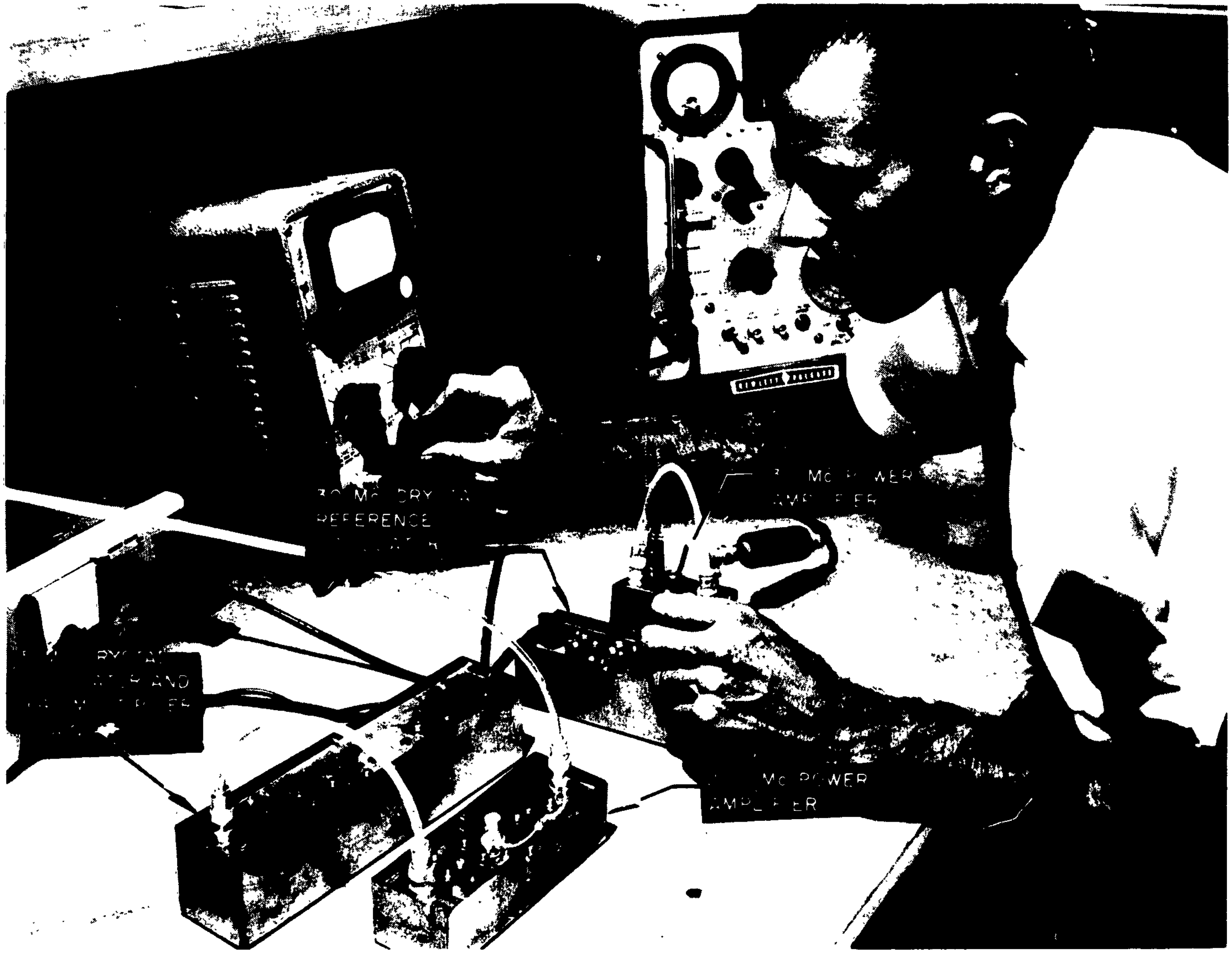

Fig. 8. Five-Megacycle Crystal Oscillator and X40 Multiplier Chain in Final Checkout

III. DEMONSTRATION PROGRAM

A. INTRODUCTION

The space radio facility boresight range between Building F, El Segundo, and San Pedro Peak, Palos Verdes (Fig. 9), can be used for performing various feasibility demonstrations of the experimental program. Because funds have already been allotted for prior requirements of the millimeter-wave observatory program, this range also presents an economical means for conducting experiments of the millimeter-wave communications techniques program.

Initially, a one-way communication link will be established between the transmitter at Palos Verdes and the receiver at Building F. This will minimize the influence of Palos Verdes radar transmissions on the early stages of receiver testing. If desirable, a two-way link may be established at a later date provided adjacent radar harmonics do not present significant interference problems.

The experiments performed on the communication link will be directed toward determining the problems associated with applying the primary uniqueness of millimeter waves, which is their extremely high frequency. This high frequency permits: the attainment of extremely narrow beamwidths with antennas of small physical size and provision of a carrier for very high data-rates. In addition to demonstrating the laboratory techniques which will exploit the uniqueness of millimeter waves, the possibilities for further experimental effort include: measurement of propagation delay variations as a function of atmospheric conditions; more precise quantitative determinations of atmospheric attenuation and frequency location of "windows"; effects of multipath and measurement of the improvements in eliminating these effects at higher frequencies.

B. EQUIPMENT

The antennas at each terminal of the link will consist of World War II surplus 60-in. searchlights employed as reflector elements and equipped with

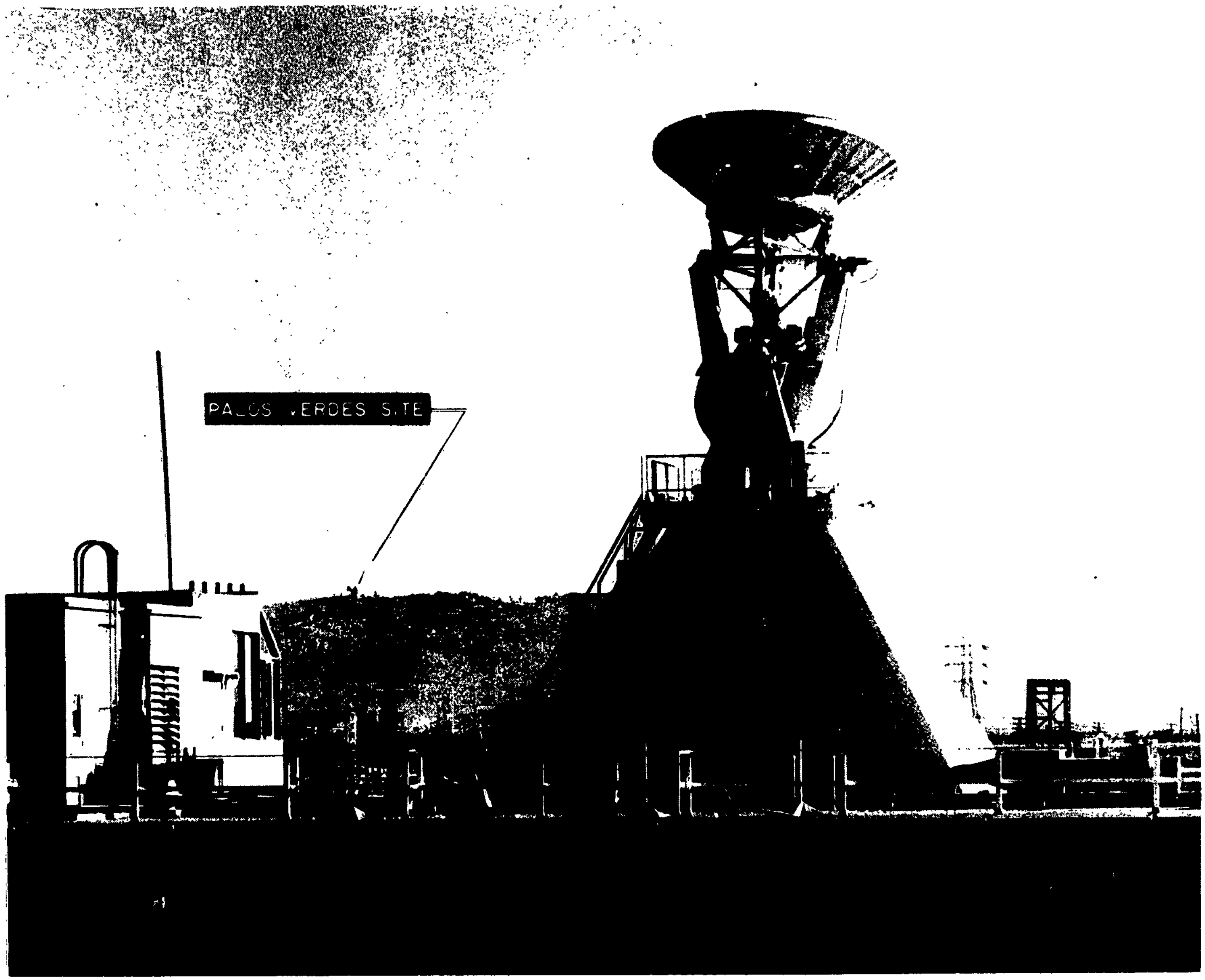

Fig. 9. Boresight Range, San Pedro Peak, Palos Verdes, Viewed through the Space Radio Facility, El Segundo

appropriate feeds. The detailed configuration of the transmitter and receiver will be determined from continuing laboratory investigations based on the preliminary efforts described in previous sections. In general, it is expected that the transmitter will be essentially a millimeter-wave klystron that is phase-locked to a stable reference with FM modulation introduced on the klystron frequency-control element. A double or triple-conversion superheterodyne receiver, with local oscillator injection signals derived from a stable reference, will be used. Initial modulation and signal processing equipment will consist of conventional multipurpose laboratory test equipment augmented with appropriate circuit elements which will be developed as needed.

C. PALOS VERDES FACILITY

Permission is presently being sought; from government agencies responsible for the Palos Verdes radar site, to install a skid-mounted, two-story structure. The structure under consideration, owned by Douglas Aircraft Corporation, is a wood-frame, two-story surplus tool crib having a floor size of 10 by 20 ft. It is planned that this structure be refurnished with appropriate lighting, electrical outlets and flooring. Half of the upper story will be used for the space radio facility antenna boresight transmitter and optical alignment searchlights. The other half is available for one terminal of the demonstration system of this program. The first floor is available for storage and/or office space. It is expected that all negotiations related to this structure and plans for its installation will be completed by the end of September, 1963.

D. AEROSPACE - EL SEGUNDO FACILITY

The Building F roof-top facilities available to this program consist presently of only a stable platform on which searchlight-type antennas and other equipment may be mounted. The platform forms a triangle with 30-ft and 25-ft perpendicular sides. The base is a heavy I-beam structure which was used for diurnal-tilt measurements of the building related to the space radio facility installation. Wood decking is secured to the metal beams to provide a platform area of 375 sq ft. Equipment can be protected against weather by construction of small housings on the platfor .

IV. MEETINGS

In order to apply most effectively the available manpower and facilities to the program, a direct survey of the programs underway at various companies and research institutions was planned. Among the laboratories chosen for visits by department personnel was the Raytheon facility at Santa Barbara. A group comprised of C. J. Carter, L. A. Hoffman, E. B. Soltwedel and H. J. Wintroub visited Raytheon on 17 June 1963.

The Raytheon Company had been active for some years in conducting research in the field of millimeter waves. Their activities were associated primarily with power sources, semiconductor devices, ferrites and microwave components. The Santa Barbara division had acquired a good capability in the development of semiconductor devices and microwave components. However, at the time of our visit they had little interest in fabricating and supplying individual components but preferred to develop complete systems. Much of their system experience had been with scanning-type receivers employing narrow-band IF amplifiers in the VHF range. Their millimeter-wave mixers were generally of the balanced type requiring handmade diodes matched through selection from large quantities. No change of emphasis or redirection of effort in the program has resulted from this visit.

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